Odour nuisance assessment of the food industry wastewater treatment plant

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Abstract. Odour nuisance generated by food industry objects is a significant problem, the result of which is often numerous complaints from local residents about the quality of air. Apart from the production process, this problem often concerns industrial wastewater treatment processes, which contribute to a large extent to the emissions of odorants from the sulphur group, including hydrogen sulphide and mercaptans. In order to estimate the odorous air quality around these types of objects, the modelling of dispersion of pollutants: odours or odorants is often used. The paper presents the results of tests on odour emission as well as hydrogen sulphide and mercaptans emission as compounds typical for waste gases from the sewage treatment process from the food industry. In order to estimate the range of odour impact, model calculations using the Polish reference model for the aforementioned substances were made. The values of annual average concentrations and frequency of odour detection thresholds for odorants and odour concentration of 1 $ou_{E/m}^3$ for odours as a mixture in a computational grid of 1400 m x 1400 m with a step of 50 m were calculated. The results showed the highest range of odour impact of mercaptans, whose value of the average annual concentration exceeded the odour detection threshold up to 700 m in the east and west direction from the emission source.

1 Introduction

The emission of gases contaminated with odorants into the atmosphere is a significant environmental problem. Among the anthropogenic sources of odour emission, the group of industrial sources is the most diversified. The most frequently represented group of them are objects of agro-food processing [1, 2]. In many cases, thermal processing of substrates takes place in the technological process. This is caused by the fact that the raw materials used in the food industry are characterized by low durability and complex organic structure, so they are partially decomposed, and thus results in the formation of volatile chemical compounds.

Both in the context of odours and individual odorants, two types of detection thresholds can be distinguished. The lower limit of the perceived odour intensity range that can be detected is the odour detection threshold. This is the minimum concentration of a substance that can trigger a sensory response in the olfactory receptor of a specific percentage of a given population, usually 50% of the cases in which the odour is detected. In this concentration,

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the odour is not necessarily correctly identified. The second characteristic threshold is the odour threshold, which refers to the lowest concentration at which the sensory effect can be correctly combined with a specific substance that is sensed by 50% of cases in the representative group [3]. For example, for hydrogen sulphide, the average geometric recognition threshold, at which the odour is correctly identified as hydrogen sulphide is 6.3 μg/m^3 [3], and the detection threshold is 0.57–1.42 μg/m^3 [4-8], hence, it is nearly 5–10 times lower.

One of the most commonly used techniques to assess the effects of odour emissions is the simulation of the topographical and meteorological data of the object in order to estimate the concentration of odours and odorants in the air using dispersion modelling tools. This method allows forecasting of distances from the emission source that plume of pollution can reach [1, 2]. In Poland, in accordance with the methodology contained in the Regulation of the Minister of the Environment of 26 January 2010 on reference values for some substances in the air, such calculations are carried out with a reference model based on the Gaussian plume model [9].

The paper presents the results of calculations of the model dispersion of odours and odorants: hydrogen sulphide and mercaptans emitted from deodorization plant at food industry wastewater treatment plant. The evaluation of the odorous impact of WWTP was made using the Polish reference model in the OPERAT FB software for the grid size of 1400 m x 1400 m and the calculation step of 50 m. The obtained results allowed to compare the odour nuisance assessment of the object due to the emission of odours and selected odorants.

2 Odours at WWTPs

Odours produced in wastewater treatment plants are the result of biological degradation of organic matter under anaerobic conditions. The odour emission may result from the fact that odorants are present in the sewage supplied to WWTPs and are released into the air during the treatment plant operation. Another possibility is the formation of odorants as a result of biological activity in wastewater. An anaerobic activity leads to the production of chemical compounds such as hydrogen sulphide, methane, ammonia, and organic compounds: mercaptans, amine, indole, skatol. Sulphurous compounds are a typical group for WWTPs, including hydrogen sulphide characterized by the smell of rotten eggs and mercaptans: methyl and ethyl mercaptans with a decaying cabbage smell, as well as propyl and butyl mercaptan with a generally unpleasant smell [10].

Table 1 summarizes the literature data on odour detection thresholds for hydrogen sulphide and mercaptans typical for emissions from WWTPs: methyl mercaptan, ethyl mercaptan, propyl mercaptan, butyl mercaptan, benzyl mercaptan. The mean value of the odour detection threshold for hydrogen sulphide and for the sum of mercaptans was used for calculations performed as part of the work.

The value of odour detection threshold determined for hydrogen sulphide in research works performed in the last twenty years ranged from 0.491 to 0.97 μg/m^3. The average value from the values in the table below was used for further analyses. In the case of mercaptans, chemical compounds typical of wastewater treatment processes have different odour thresholds (from 0.01 μg/m^3 for butyl mercaptan up to 2.16 μg/m^3 for methyl mercaptan). In order to carry out analyses in the further part of the work, the arithmetic mean from detection threshold values determined for methyl mercaptan, propyl mercaptan, butyl mercaptan, and benzyl mercaptan were used as the detection threshold value for all mercaptan mixture.

Table 1. Comparison of odour detection thresholds for hydrogen sulphide and mercaptans typical for emission from WWTPs.

References	Hydrogen sulphide [μg/m³]	Mercaptans				
		Methyl mercaptan [μg/m³]	Ethyl mercaptan [μg/m³]	Propyl mercaptan [μg/m³]	Butyl mercaptan [μg/m³]	Benzyl mercaptan [μg/m³]
[4]	0.65	2.16	0.48	0.404	0.01	0.96
[5]	0.97	0.98	-	-	-	-
[6]	0.57–1.42	-	-	-	-	-
[7]	0.57	0.14	0.022	0.404	0.01	0.96
[8]	0.491–0.946	-	-	-	-	-
Average	**0.802**	**1.093**	**0.251**	**0.404**	**0.010**	**0.96**
		0.546				

3 Materials and methods

3.1 Study site

The analysed object is an anaerobic biological wastewater treatment plant that treats wastewater from the food industry. The air from the sewage treatment plant is sucked in through the pipeline system transporting to the deodorization plant – trickle bed bioreactor. The outlet from the deodorization installation is located at an altitude of 6.600 m, and its diameter is 0.80 m. The facility is located in the southern part of Poland on the outskirts of the city above 100,000 inhabitants. In the area surrounding the plant, at a distance of approx. 100 m single- and multi-family housing estates are located, as well as industrial and agricultural areas.

Table 2 summarizes the parameters of the emitter (the outlet channel of the trickle bed bioreactor).

Table 2. Parameters of emitter.

Parameter	Unit	Value
Emitter diameter	[m]	0.8
Emitter height	[m]	6.60
Exhaust gas velocity	[m/s]	2.76
Exhaust gas flow	[m³/s]	1.39
Exhaust gas humidity	[%]	77.5
Exhaust gas temperature	[K]	303.8

3.2 Input data for modelling

In order to determine the odour concentration in the outlet channel from the trickle bed bioreactor, gas samples were taken in accordance with the methodology described in EN 13725:2007 [11]. Sampler and PET bags characterized by the lack of absorption and odour extraction were used for sampling. The other equipment used for sampling is also made of odourless materials. PET bags were conditioned prior to takeingsamples. Samples were taken at an average time of 30 s using a standard sampler CSD30.

Immediately after the collection, the samples were transferred to the Olfactometric Laboratory, where odour concentrations were determined. The measurement of the odour concentration was made using the dynamic olfactometry method in accordance with the procedures described in the EN 13725: 2007 standard [11]. A TO8 four-station olfactometer was used for the measurement together with the necessary equipment. The unit of the odour concentration is reported as the European odour unit per cubic meter (ou_E/m^3).

Measurements of the concentration of hydrogen sulphide and mercaptans were made using the dynamic dosimetry method using Dräger indicator tubes used for instantaneous measurements.

Table 3 lists the concentrations of odorants - hydrogen sulphide and mercaptans, the odour concentration, expressed in European odour unit per cubic meter. On the basis of the determined concentrations of pollutants in the off-gas and gas flow rate, the emission value for the above mentioned substances was determined.

Table 3. Data on the emission of odour and odorants (hydrogen sulphide and mercaptans) from the analysed object.

Name of pollutant	**Pollutant concentration** **[ou_E/m^3] - odours** **[mg/m^3] – odorants**	**Pollutant emission** **[ou_E/s] – odours** **[mg/s] - odorants**
Odours	228393	317466
Hydrogen sulphide	69.53	96.65
Mercaptans	196.32	272.44

3.3 Model studies

The calculations were carried out with the Polish reference model according to the methodology contained in the Regulation of the Minister of the Environment of 26 January 2010 on reference values for certain substances in the air in OPERAT FB software. The location and parameters of odour and odorant emission sources were determined, the aerodynamic roughness of the terrain was determined and the meteorological parameters for the designated area were selected.

Using the model, for a computational grid of 1400 m x 1400 m and a computational step of 50 m, the average annual concentration of odour and average annual concentration of analysed odorants (mercaptans and hydrogen sulphide) to the reference value of 1 ou_E/m^3 for odours and to odour detection threshold for odorants calculations were made. For the same assumptions, calculations of the frequency of exceedances of the odour concentration of 1 ou_E/m^3 and odour detection thresholds for the analysed odorants during the year were carried out.

4 Results and discussion

The calculations carried out in the OPERAT FB software using the Polish reference model have made it possible to estimate the odour nuisance impact of the analysed object. For each pollutant, calculations of the average concentrations and frequency of exceeding one-hour concentrations were made. Based on the obtained results, it can be concluded that the object may be a cause of odour nuisance for residents of nearby buildings. Figure 1–3 shows the results of calculations of pollutants – odours (Fig. 1), hydrogen sulphide (Fig. 2) and mercaptans (Fig. 3) dispersion.

In order to perform model calculations for hydrogen sulphide and mercaptans, according to data included in Table 1, the odour detection threshold was assumed at the level of 0.802 μg/m^3 and 0.546 μg m^3, respectively.

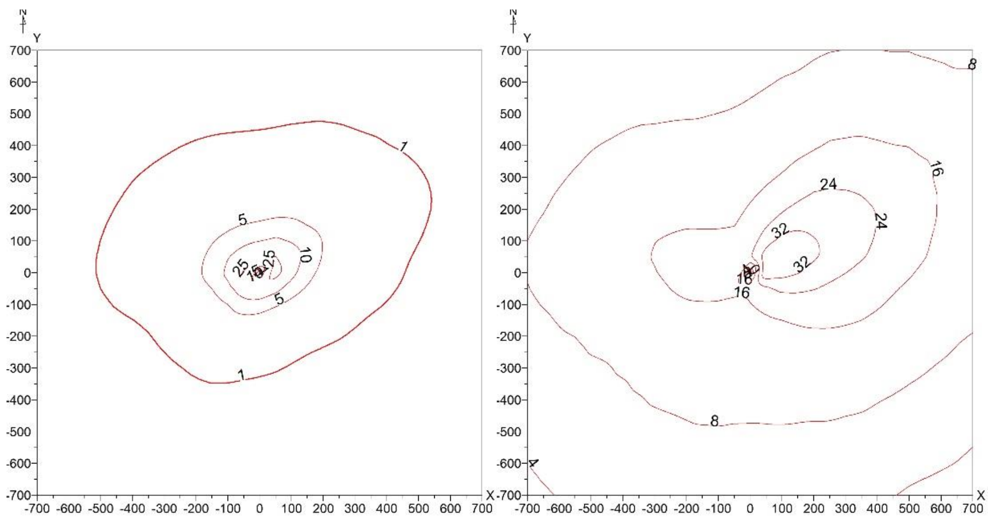

Fig. 1. Isolines of an average annual odour concentration (exceedance threshold of 1 ou$_E$/m^3) – the left side. Isolines of the frequency of exceeding the one-hour odour concentrations (limit value 1 ou$_E$/m^3) – the right side.

The model calculations of the average annual odour concentration (Figure 1) showed the highest range of the odour impact in the eastern direction – 550 m from the emission source. The range of impact in the northern, western and southern directions was 450 m, 500 m, and 350 m, respectively. Also, the frequency of exceeding the one-hour odour concentrations reached the highest values in the east direction and amounted to about 14% at a distance of 700 m from the emission source. In the north, west and east directions, the frequency of exceedances at a distance of 700 m from the emission source was 6%, 8%, and 6%, respectively.

Modeling the dispersion of hydrogen sulphide (Figure 2) around the emitter showed the least impact on the odour nuisance compared to the remaining analysed pollutants. Calculations of the average annual hydrogen sulphide concentration showed the highest range of the odour impact in the eastern direction – 350 m from the emission source. The range of impact in the northern, western and southern directions was 250 m, 275 m, and 200 m, respectively. Also, the frequency of exceeding the one-hour hydrogen sulphide concentrations at a level of odour detection threshold reached the highest values in the east direction and amounted to about 5% at a distance of 700 m from the emission source. In the north, west and east directions, the frequency of exceedances at a distance of 700 m from the emission source was 3%, 4%, and 3%, respectively.

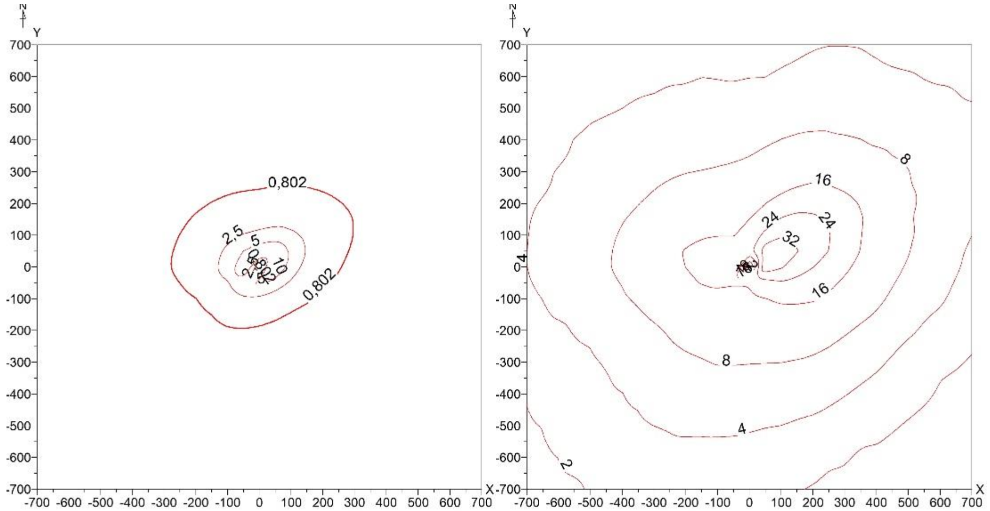

Fig. 2. Isolines of an average annual concentration of hydrogen sulphide (up to odour detection threshold for hydrogen sulphide) – the left side. Isolines of the frequency of exceeding the one-hour concentrations at the level of odour detection threshold for hydrogen sulphie – the right side.

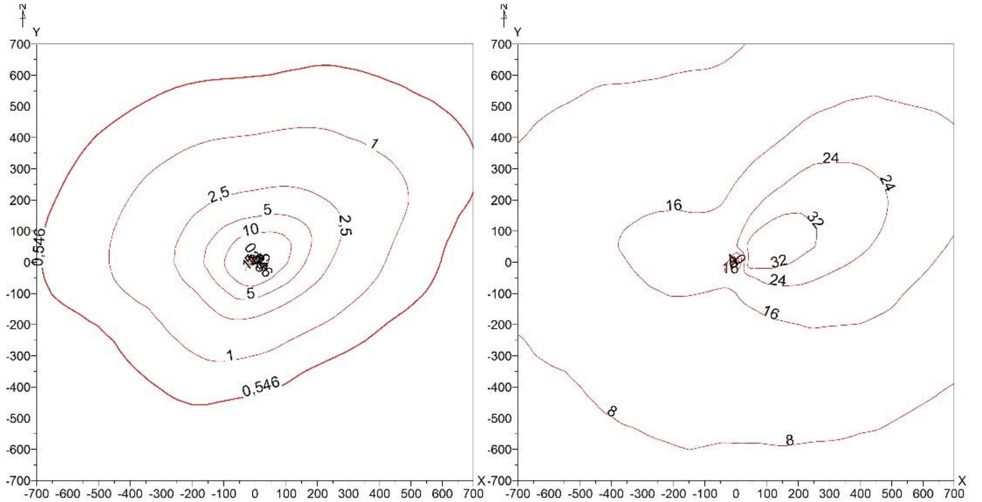

Fig. 3. Isolines of an average annual concentration of mercaptans (up to odour detection threshold for mercaptans) – the left side. Isolines of the frequency of exceeding the one-hour concentrations at the level of odour detection threshold for mercaptans – the right side.

Model calculations carried out showed that among the analysed pollutants, mercaptans have the largest range of the odour impact Calculations of the average annual mercaptans concentration showed the highest range of the odour impact in the eastern direction – 350 m from the emission source. The range of impact in the northern, western and southern directions was 250 m, 275 m, and 200 m, respectively. Also, the frequency of exceeding the one-hour mercaptans concentrations at a level of odour detection threshold reached the highest values in the east direction and amounted to about 5% at a distance of 700 m from the emission source. In the north, west and east directions, the frequency of exceedances at a distance of 700 m from the emission source was 3%, 4%, and 3%, respectively.

5 Summary and conclusions

Water and sewage management is one of the main sources of odour nuisance of food industry facilities. The main pollutants that may affect the odour impact of these objects include sulphurous compounds: hydrogen sulphide and mercaptans. The range of the odour impact depends not only on the odour detection thresholds of the individual compounds contained in the gases but also on the overall composition of the mixture, in which some compounds can affect the aroma parameters (intensity, hedonic quality) of others. For this reason, such an important element of the odour impact assessment is the use of methods allowing the determination of the odour concentration and the inclusion of odours as a mixture.

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References

1. M. Szklarczyk, J. Zwoździak, I. Sówka, *Industrial sources of odour emissions, Współczesna problematyka odorów* (praca zbiorowa pod redakcją Szynkowskiej i Zwoździaka, 54–85, Wydawnictwo Naukowo-Techniczne, Warszawa, 2010)
2. I. Sówka, *Metody identyfikacji odorotwórczych gazów emitowanych z obiektów przemysłowych* (Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław, 2011)
3. W. van Niekerk, M. Fourie, *Odour Thresholds and Odour Descriptors of Substances. Measured at the EnviroServ Shongweni Landfill Site* (INFOTOX (Pty) Ltd, Report No. 011-2017, 2017)
4. A. Talaiekhozani, M. Bagheri, A. Goli, M. R. T. Khoozani, J. Environ. Manage. **170**, 186–206 (2016)
5. D. Glindemann, J. Novak, J. Witherspoon, Environ. Sci. Technol. **40**, 202–07 (2006)
6. M. A. McGinley, C. M. McGinley, Water Sci. Technol. **50**, 4, 75–82 (2004)
7. Y. Nagata, *Measurement of Odor Threshold by Triangle Odor Bag Method In Odor Measurement Review* (Japan: Office of Odor, Noise and Vibration Environmental Management Bureau, Ministry of the Environment, Government of Japan, 118–12, 2003)
8. D. Mannebeck, H. Mannebeck, Gefahrstoffe Reinh. Luft. **62**, 135–40 (2002)
9. Regulation of the Minister of Environment dated 26 January 2010 on reference values for some substances in the air. (Journal of Laws 2010, no. 16, item 87).
10. B. Rajbansi, *Control of specific odorants from Sewage Treatment Plants STP development and validation of the control scheme* (Ph.D. thesis, Jadavpur University, Kolkata, 2013)
11. PN-EN 13725:2007 standard: Air quality. Determination of odour concentration, with the use of dynamic olfactometry method